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SOME RECENT INVESTIGATIONS IN SUGAR-BEET BREEDING

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(WITH FIFTY-ONE FIGURES)

Introduction

This investigation was made for the purpose of ascertaining certain facts and principles which have an important bearing upon methods of breeding. The introduction of more economical methods, based upon correlated characters or upon a better knowledge of scientific principles, would aid materially in the improvement of beets.

The efficiency of breeding methods depends largely upon the soundness of the scientific principles on which they are based. Unfortunately, many principles of breeding are still obscure, and even doubtful principles are employed as the basis of improving or originating a variety. Biologists who believe that improvement results from a gradual accumulation of small variations practice continuous selection, while those who adhere to a belief in improvement by the use of a few exceptional, prepotent individuals work with larger numbers and depend upon the isolation of mutations. In studying the effects of our own methods we have endeavored to determine whether improvement is accomplished through continuous selection, and also whether prepotent plants of exceptional quality occur within the limited range of our cultures.

A sugar-beet variety as ordinarily developed and maintained differs from a variety of other crops in that it consists of a number of

families which are preserved from generation to generation by continuous selection. Whenever a family shows deterioration it is discarded, but, as new families are annually added, the number composing the variety is not materially altered.

One of the most costly operations practiced in sugar-beet breeding is the determination of the so-called best roots, either for starting families or as representatives of families already established. This is accomplished by chemically analyzing the individual roots of each family and grading them upon the basis of size, shape, and percentage of sugar. The few best roots are saved to preserve the family and continue the process of improvement, while the remainder are thrown into a mixed lot and used for growing stock seed. A fairly good conception of the number of analyses made in commercial work of this kind is afforded by the records of a single European beet-seed company who analyze over 300,000 individual beets a year. The cost of making these analyses forms a large part of their operating expenses. Yet, aside from the theory that "like begets like," there seems to be little evidence that these highly selected roots are better for breeding purposes than the discards. It has apparently been assumed upon theoretical grounds that a high percentage of sugar tends to be transmitted, and therefore is the most important quality of a mother root without regard to the possibility of its being a fluctuating character and nowise indicative of the average quality of the plant's progeny.

Real differences between individuals and varieties are often obscured by variations caused by irregularities of the soil, which makes it difficult to distinguish hereditary differences from temporary differences and thus complicates the question of methods. The comparative efficiency of different methods has been treated somewhat in detail in another paper,[1] but the effect of environment on the behavior of consecutive check and progeny rows will be graphically illustrated here, as it presents a number of interesting phenomena which have an important bearing on the results of this investigation.

[1] A contribution to the use of checks and repeated plantings in variety tests.

While only a few of the beet breeders' problems have been outlined, they are fundamentally important and need investigation for the purpose of developing more economical methods.

Character of material employed

The material employed consisted of (1) an American variety of sugar-beets, known as Morrison's Kleinwanzleben; (2) an unnamed variety originated at Madison, Wisconsin, in 1912 by making selections from 11 foreign varieties and designated for convenience in reference as Madison Original Selections; (3) 5 South Dakota varieties bred for several years at Brookings, South Dakota; and (4) an old, well-established European variety, Kleinwanzleben's Original.

Morrison's Kleinwanzleben is composed of a large number of separate strains or families which have been preserved and improved by continuous selection. Ten years were devoted to this work at Fairfield, Washington, and 3 years at Madison, Wisconsin. The records obtained from these families and their individual components have furnished all the progeny row data not otherwise accounted for in the tables and figures.

Madison Original Selections are composed of beet families which originated from roots containing 18–26 per cent sugar. As no records of their performance were available until 1914, they have contributed few data to this paper.

The 5 South Dakota varieties used in our experiments at Brookings were originated by selecting rich roots from foreign stock and making subsequent tests and selections primarily upon the basis of a high percentage of sugar. About an equal number of roots were taken at random from each of these varieties to compile the data from this material, which are used in table I and graph A of fig. 51.

Kleinwanzleben's Original was the variety planted in the check rows. It is one of the most uniform, most highly bred, and most widely used varieties of sugar-beets on the market. The seed was taken from an unopened bag, sealed by the Rabethge & Giesecke Company at their plant, in order to increase the probability of

its all being grown in one locality under similar environmental conditions, and thoroughly mixed before being used, to enhance its uniformity.

Investigation

CONTROL OF CROSS-FERTILIZATION.—Undesirable cross-fertilization was avoided by planting the seed-beets of approximately equal qualities in isolated groups, a practice commonly followed in beet breeding. At Fairfield the quality was determined from the percentage of sugar, but at Madison a somewhat different method of classifying the roots was employed. As small beets are richer on the average than large beets, the regression coefficient was determined between weight and percentage of sugar and a correction made for size. Roots of equivalent value, as determined from both size and percentage of sugar, were then planted together at distances of 40–80 rods from other groups. However, at Brookings all the selected seed-beets of each variety were planted in a group and allowed to cross-fertilize with one another but not with beets of another group.

CHEMICAL CONTROL.—All the chemical work was done by experienced sugar chemists, the personnel consisting of JOSEPH F. REED at Fairfield, GUY YOUNGBERG at Brookings, and W. B. CLARK and assistants at Madison.

The sugar determinations of beet families were made at Fairfield by collecting roots at regular intervals in the row, grinding them to a fine pulp, and making composite analyses of the samples. A somewhat different method of procedure was followed at Madison. The quantity of sugar was first determined for each individual root and the sum of the quantities was then divided by the total weight of roots.

FIELD CONDITIONS UNDER WHICH THE MATERIAL WAS GROWN.—The experimental fields were fairly uniform with respect to soil-type, fertility, drainage, and previous cropping, and all field operations, as plowing, planting, thinning, cultivating, etc., were always performed in as short a time as circumstances would permit, in order to prevent the introduction of unequal factors.

SELECTION OF FOUNDATION STOCK.—The choosing of a variety as foundation stock often has as much to do with the improvement

of a crop as subsequent selections. Sugar-beet varieties are seldom distinguishable from one another morphologically, however, and as they have nearly the same descent, some doubt may be expressed regarding the existence of real variety differences. In order to determine the truth of this hypothesis, 78 families of Morrison's Kleinwanzleben,[2] which made the best records for percentage and yield of sugar at Madison in 1912, and 52 families of Madison Original Selections were used in a comparative merit test in 1914.

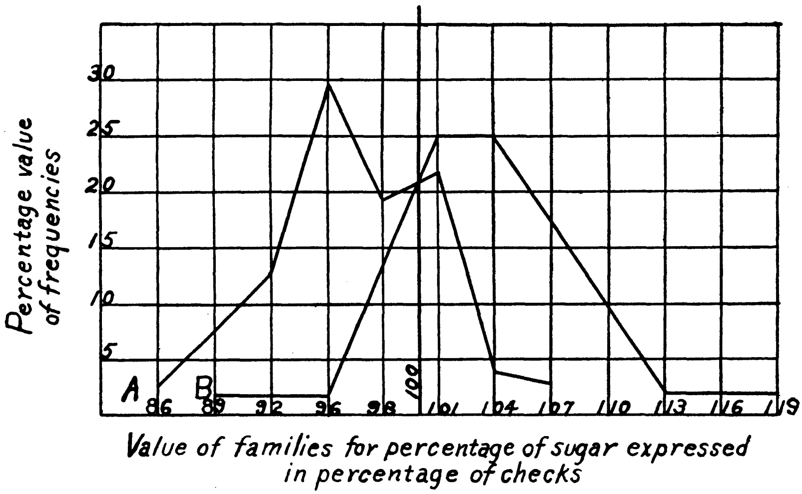

FIG. 1—Comparison of two kinds of sugar-beet material used as foundation stock.

A progeny row of each family (seed of a single beet) was planted between two check rows of Kleinwanzleben's Original. When the beets were harvested, each progeny row was compared with the average of its two contiguous checks by giving the latter a value of 100 and computing the value of the progeny row upon this basis. In fig. 1 the vertical line represents the values of the check rows for percentage of sugar; the frequency polygons *A* and *B*, Morrison's Kleinwanzleben and Madison Original Selections, respectively. The frequencies were reduced to percentages by

[2] In 1912 these families were grown from seed of Fairfield roots containing 20–22 per cent sugar.

dividing each class by the total number of variates in the population; hence the graphs are comparable.

Fig. 1 shows the superiority of Madison Original Selections over Morrison's Kleinwanzleben at Madison, where the percentage of sugar is normally low and a higher percentage is the chief desideratum. Hence the foreign varieties from which the Madison Original Selections were made are better as foundation stock at Madison than the variety Morrison's Kleinwanzleben. One or two plantings of each variety would hardly suffice to show this difference, but the large number of replications used were sufficient to establish it with a fair degree of certainty.

Morrison's Kleinwanzleben has been selected for a high yield of sugar, and in tests with foreign varieties in several different localities in the United States it has usually stood preeminent in this respect. In a 5 years' test at Fairfield, Washington, where it was bred for 10 years, it was equal to Kleinwanzleben's Original and better than 11 other varieties in percentage of sugar and ranked first in yield of sugar. At Madison, however, it is not well adapted to the breeders' needs as foundation stock. Although it was superior to Kleinwanzleben's Original in yield of sugar in 1913 (cf. fig. 30), it was inferior to it in 1912. It was relatively low in percentage of sugar in comparison to the checks (KWO) in 1912, and continued to maintain this position in its second year's test after all the supposedly poor families had been eliminated.

Selection of mother roots.—The selection of mother roots for the purpose of starting a new family of beets or improving one already established is usually made upon the basis of size, shape, percentage of sugar, and relative freedom from mineral substances which interfere with the extraction of sugar. The coefficient of purity is not usually determined for breeding purposes, however, as only roots containing a high percentage of sugar are saved and they are almost invariably characterized by high purity. As size and shape are distinguished by physical selection, percentage of sugar is the only character determined chemically.

Variability of material from which mother roots were selected.—The variability of beet roots in percentage and quantity of sugar is ample for selection, as may be seen in table I.

The average variability of the roots as shown by the standard deviations was 1.25–1.59 per cent sugar and 19.28–37.99 grams of sugar. Measured by the coefficient of variability, this amounts to 6–12 per cent of the mean for percentage of sugar and 18–50 per cent for quantity of sugar, which are fairly large differences for averages.

TABLE I

VARIABILITY OF SUGAR-BEET ROOTS IN PERCENTAGE AND QUANTITY OF SUGAR

Station	Year	Number of roots analyzed	Mean	Standard deviation	Coefficient of variability
Percentage of sugar in roots					
Fairfield......	1907	230	20.15±0.056	1.26±0.039	6.25
"	1909	400	20.37±0.048	1.47±0.035	7.22
"	1910	400	17.34±0.044	1.31±0.031	7.55
"	1910	400	18.76±0.042	1.25±0.029	6.66
Brookings.....	1911	3784	17.67±0.017	1.59±0.012	8.99
Madison......	1912	500	12.86±0.047	1.55±0.033	12.06
"	1913	500	14.24±0.041	1.35±0.029	9.46
Quantity of sugar per root in grams					
Madison......	1912	500	98.46±1.146	37.99±0.810	38.58
"	1913	500	54.02±0.807	26.76±0.570	49.53
Fairfield......	1910	126	104.61±1.191	19.85±0.850	18.97
"	1910	147	104.90±1.077	19.28±0.770	18.38
"	1909	231	113.68±1.134	25.43±0.790	22.37
Brookings.....	1911	3784	79.87±0.266	23.94±0.186	29.97

The range of variation for percentage of sugar in individual beets is not shown in table I, but varies ordinarily from about 8 to 24. Small, immature beets frequently contain less than 8 per cent sugar, and occasionally a root is found which contains more than 24 per cent. We found one beet at Madison which showed 26 per cent sugar in 2 separate analyses. Another small root, so small in fact that it had to be bored lengthwise through the center to obtain a sample of pulp, contained 30 per cent sugar.

RELATIONSHIPS BETWEEN A FEW COMMONLY DETERMINED CHARACTERS OF THE ROOT AND ITS YIELD OF SEED.—A knowledge of the relationship of such characters as root weight and percentage of sugar to seed production is essential to intelligent selection. Very

frequently beet roots are separated into selects and discards on small differences. A satisfactory method of predicting seed yields would not only alter these results but would furnish a means of obtaining sufficient seed to make several plantings of each family.

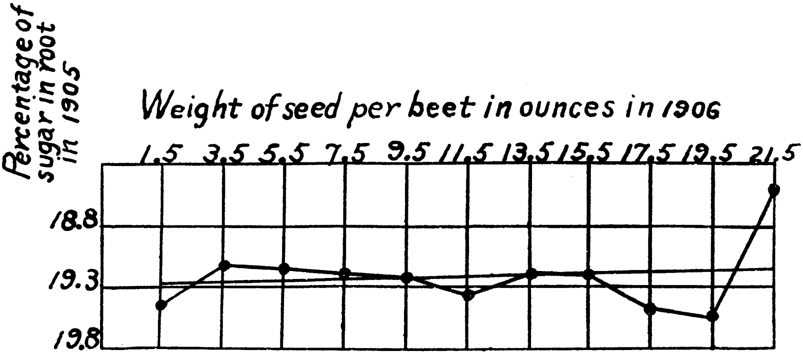

FIG. 2.—To accompany table II

Tables II–XI (summarized on p. 463) and figs. 2–11 show the relationships which obtain between these characters. Some of the tables show slight irregularities, but they are not sufficient to invalidate the results. The effects of the irregularities may be seen in

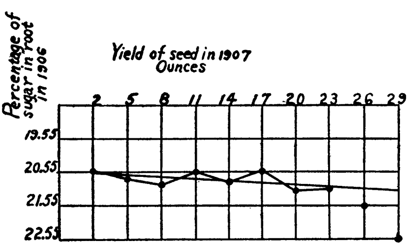

FIG. 3.—To accompany table III

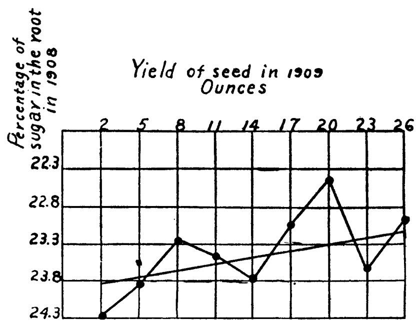

FIG. 4.—To accompany table IV

the deviation of the dots representing the empirical means of the separate classes from the straight line regressions. The divergence is not marked except where the numbers are small. Moreover, the general trends of the broken lines connecting the empirical means agree fairly well in direction with the straight line regres-

sions. The distributions are fairly regular, therefore, and the coefficients are probably reliable.

When due consideration is given to probable errors,[3] the coefficients show no correlation between weight, percentage of

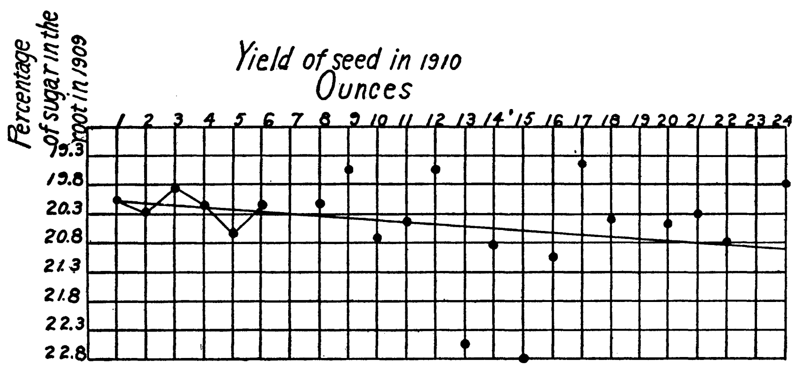

FIG. 5.—To accompany table V

sugar, or quantity of sugar of the seed beet and its yield of seed. This refers to beets of ordinary sizes such as are grown for factory use. Very small beets, 0.5–2 inches in diameter (stecklings), form a little less seed per plant than large roots, although they grow to

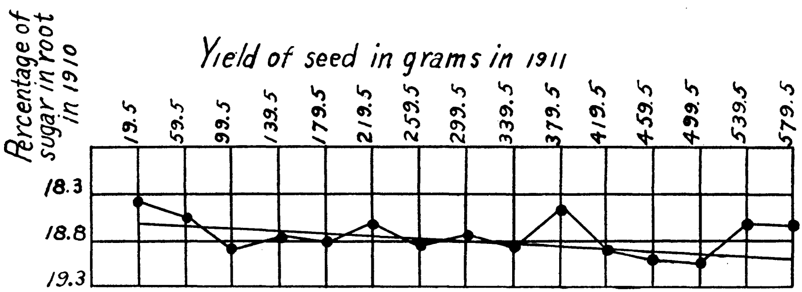

FIG. 6.—To accompany table VI

nearly normal size while producing seed. There is little doubt regarding the absence of correlation between these characters, as the tables cover a number of years and the results all lead to the

[3] The biometrical constant should exceed 3–4 times the probable error to have significance.

same conclusion. However, BARTOS[4] has found that seed production decreases as percentage of sugar increases. His average differences are only 3.3 and 8.6 per cent, however, and in the absence of probable errors we have no means of determining whether they bear any significance.

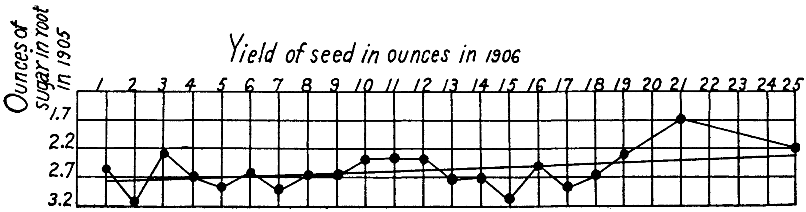

FIG. 7.—To accompany table VII

If percentage of sugar were negatively correlated with seed yield, as BARTOS believes, it would constitute an undesirable relationship. Even positive correlation between percentage of sugar and seed yield, or between weight of root and seed yield, would form a less desirable relationship than the absence of correlation, as high percentage is correlated with low yield and high tonnage with low purity. Maximum sugar production is dependent upon both percentage and tonnage, and consequently cannot run to either extreme. Positive correlation between extractable sugar and seed yield, however, would constitute a very desirable relationship, as selection for maximum sugar production would also tend to increase the seed yield.

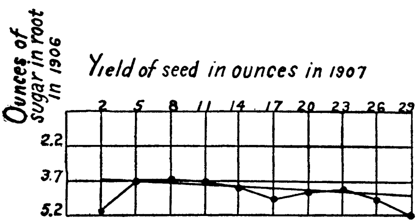

FIG. 8.—To accompany table VIII

RELATIONSHIP BETWEEN A ROOT'S YIELD OF SEED AND THE PERCENTAGE OF SUGAR IN ITS PROGENY.—No distinction between individual sugar-beet plants can safely be made in the seed generation until we learn what relationship exists between a root's yield of seed and the average sugar-producing capacity of its progeny.

[4] BARTOS, V., Je zucherhaltiger die Rübensorte ist desto kleinere Samenfruchtbarkeit hat sie. Cukrovarnicke Listy, December, 1908; rev. Bl. Zucherrübenbau **16**: 93. 1909.

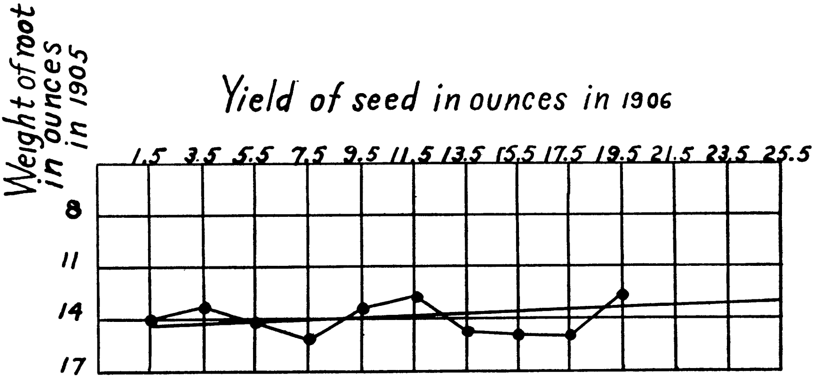

FIG. 9.—To accompany table IX

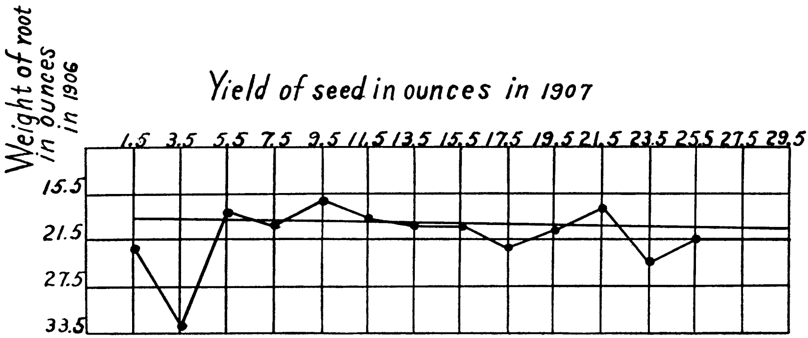

FIG. 10.—To accompany table X

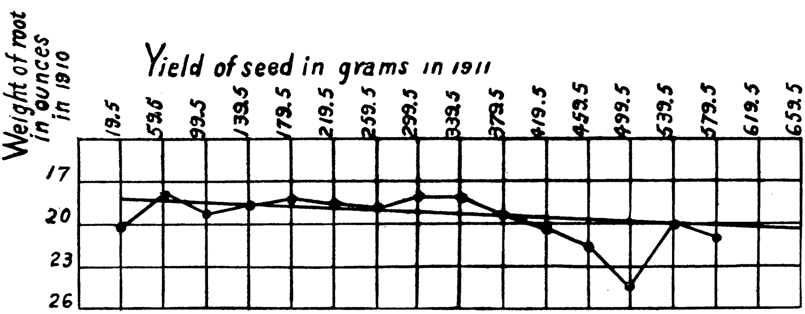

FIG. 11.—To accompany table XI

Tables XII and XIII disclose this relationship. In the experiment from which the records were obtained, the seed of each plant was

TABLE XII

RELATIONSHIP BETWEEN A BEET'S YIELD OF SEED AND THE AVERAGE PERCENTAGE OF SUGAR IN ITS PROGENY; YIELD OF SEED IN 1912

Centers of percentage of sugar classes of 0.5 per cent range in progeny of 1913	Centers of weight classes of 25 gm. range											
	162.5	187.5	212.5	237.5	262.5	287.5	312.5	337.5	362.5	387.5	412.5	Totals
13.0	1*	1	0	0	0	0	0	0	0	0	0	2
13.5	4	1	0	1	0	0	0	0	0	0	0	6
14.0	3	1	1	3	3	0	0	1	0	0	0	12
14.5	9	5	1	1	0	2	0	0	0	0	0	18
15.0	6	2	4	2	1	0	0	0	0	0	0	15
15.5	10	9	5	4	1	0	0	0	0	0	0	29
16.0	3	8	2	3	0	0	1	1	0	0	1	19
16.5	8	3	3	2	1	0	0	0	0	0	0	17
17.0	3	1	0	0	0	0	0	0	0	0	0	4
17.5	1	1	0	0	1	0	0	0	0	0	0	3
Totals	48	32	16	16	7	2	1	2	0	0	1	125

Mean yield of seed, 198.5 gm.; mean percentage of sugar, 15.32; standard deviation in yield of seed, 43.405 gm.; standard deviation in percentage of sugar, 0.996; coefficient of correlation, −0.013.

* Number of beets in the classes in 1912.

TABLE XIII

RELATIONSHIP BETWEEN A BEET'S YIELD OF SEED AND THE AVERAGE VALUE OF ITS PROGENY FOR PERCENTAGE OF SUGAR EXPRESSED IN PERCENTAGE OF THE CHECKS; YIELD OF SEED IN 1912

Percentage of sugar in progeny divided by percentage of sugar in checks in 1913	Centers of weight classes of 25 gm. range											
	162.5	187.5	212.5	237.5	262.5	287.5	312.5	337.5	362.5	387.5	412.5	Totals
83.5	0	1	0	0	0	0	0	0	0	0	0	1
85.5	3*	0	3	0	0	0	0	0	0	0	0	6
87.5	4	7	0	3	1	0	0	0	0	0	0	15
89.5	6	6	3	0	1	0	0	2	0	0	1	19
91.5	8	6	2	4	1	0	1	0	0	0	0	22
93.5	13	4	4	2	2	1	0	0	0	0	0	26
95.5	5	3	2	2	1	0	0	0	0	0	0	13
97.5	3	2	1	4	0	0	0	0	0	0	0	10
99.5	3	1	1	0	1	1	0	0	0	0	0	7
101.5	3	2	0	1	0	0	0	0	0	0	0	6
Totals	48	32	16	16	7	2	1	2	0	0	1	125

Mean yield of seed, 198.5 gm.; mean value of progeny, 92.6 per cent of percentage of sugar contained in their checks; standard deviation in yield of seed, 43.405 gm.; standard deviation in value of progeny 14.07 per cent of percentage of sugar contained in their checks; coefficient of correlation, −0.010.

* Number of beets which produced seed in 1912 and progeny in 1913.

sown in a progeny row between 2 check rows of Kleinwanzleben's Original. The relationship between seed yield and percentage of sugar was determined from the data both with and without the use of checks. In table XII actual percentages of sugar are recorded in the horizontal columns, but in table XIII the values occupying these columns were obtained by dividing the percentage of sugar of each progeny row by the average percentage of sugar of its 2 contiguous checks. As the 2 tables were compiled from the same data they are alike, except that table XII shows the relationship between seed yield and percentage of sugar when no checks were used, and table XIII when every alternate row was employed as a check.

The tables show no correlation between a beet's yield of seed and the average percentage of sugar in its progeny. The application of this fact to sugar-beet breeding is obvious, as extensive selections may be made for freer seed production without danger of sugar deterioration. Moreover, it affords an opportunity to reverse the order of selection by making the chief eliminations in the seed generation and thus greatly reduce the amount of chemical work and increase the effectiveness of the working funds.

TRANSMISSION OF SELECTED QUALITIES OF MOTHER ROOTS.—Mother roots are selected chiefly on the basis of size, shape, and percentage of sugar, because these qualities are desired in the progeny and there is a popular belief that they are inherited, but we really know very little regarding the transmission of such characters. In the early period of beet breeding they appeared to improve through selection, but this was at a time when the material was very variable and full of distinct physiological species. Improvement probably resulted from the isolation of these species, although the selections were made with a view to improving the characters. Today it is quite different. The poorer physiological species have gradually been eliminated and all varieties are now much alike. Moreover, such root characters as size and percentage of sugar—and incidentally this includes total sugar content—are markedly influenced by the environment. Consequently large fluctuations occur which are indistinguishable from hereditary differences. The fluctuations probably characterize the supposedly

best beets, in which case the cost of analyzing mother roots is an absolute waste of money. Tables XIV–XXV (summarized on p. 463) and figs. 12–23 show the extent to which we have found

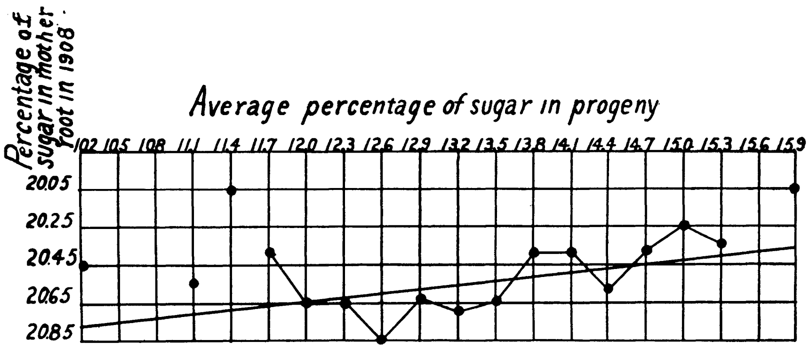

FIG. 12.—To accompany table XIV

weight, percentage of sugar, and total sugar content of the root to be transmitted to the progeny.

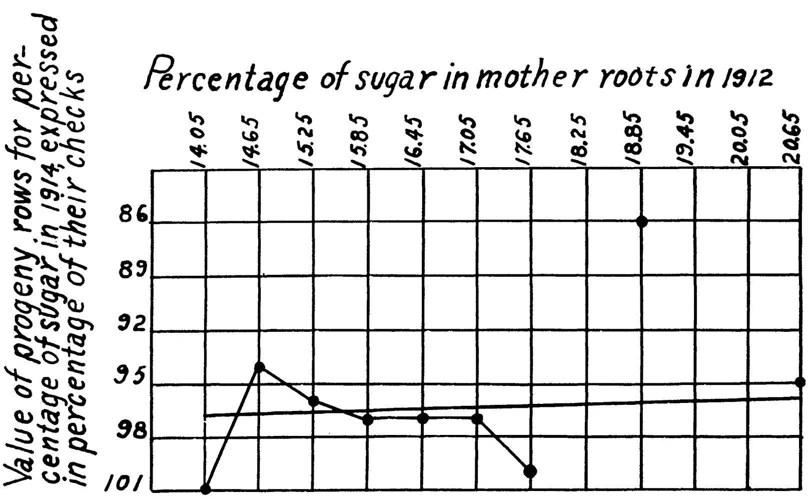

FIG. 13.—To accompany table XV

The results show no correlation between percentage of sugar, weight, or sugar content of the root and the average value of the same quality in its progeny. There is no constant relationship

between the weight of the mother root and the average percentage of sugar or the average sugar content of its progeny roots. Moreover, exceptionally good roots transmit no different qualities than

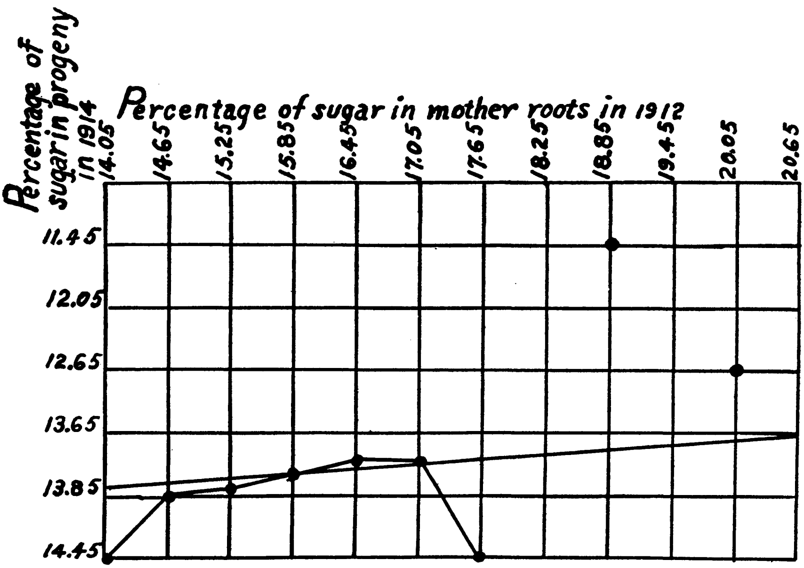

FIG. 14.—To accompany table XVI

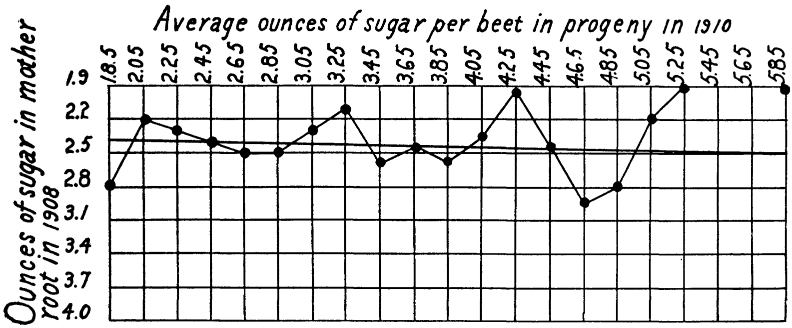

FIG. 15.—To accompany table XVII

do average roots. In fact, the poorest roots made as good progeny records as the best roots. While cross-fertilization may have had an equalizing tendency upon the qualities, real differences could hardly be eliminated in one generation, as both good and

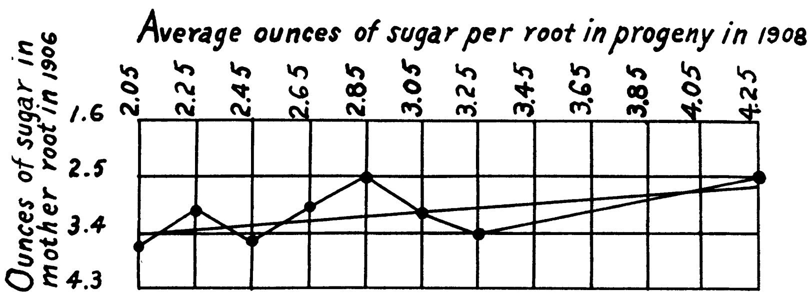

FIG. 16.—To accompany table XVIII

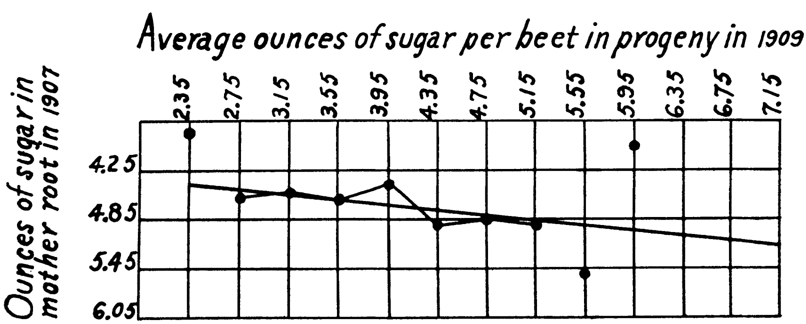

FIG. 17.—To accompany table XIX

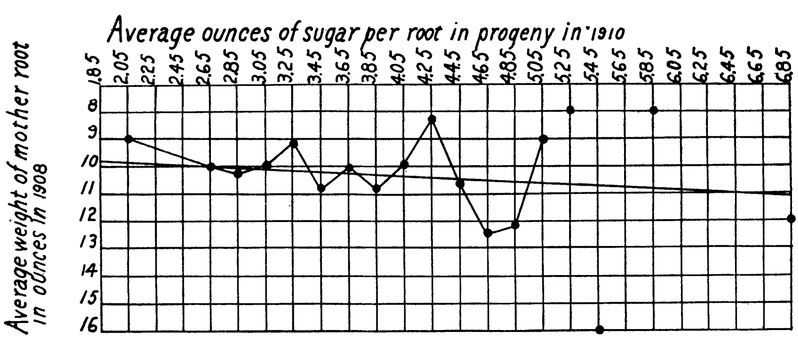

FIG. 18.—To accompany table XX

poor plants would receive pollen of equal average quality, and hence the better mothers should produce the better average progeny. Moreover, the fact that insects visit several flowers before leaving a plant probably causes a considerable percentage of selfing, even

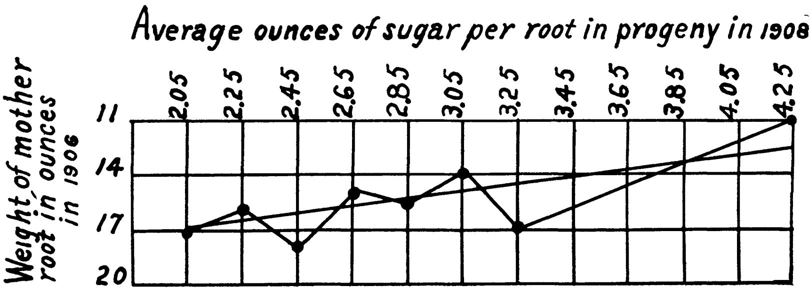

FIG. 19.—To accompany table XXI

though the plant may prefer foreign pollen. If hereditary differences occur in mother roots and are transmitted to their progeny, they are certainly obscured by fluctuations caused by irregularities of the soil, which influence the qualities of both mother root and progeny, and thus baffle the breeder's attempt to discover real differences. By planting each family 10–20 times and using a considerable number of checks it may be possible to distinguish hereditary differences between their progeny, but this would hardly apply to mother roots. In fact, these results seem to condemn the customary practice of selecting mother roots by current physical and chemical means. Taking roots at random would certainly be much cheaper and apparently fully as effective.

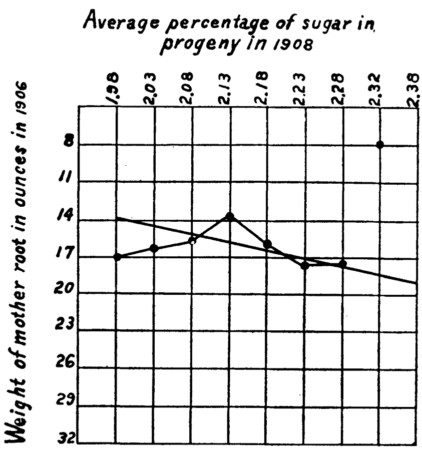

FIG. 20.—To accompany table XXII

SELECTION OF FAMILIES.—Sugar-beet families are selected upon the basis of percentage and yield of sugar. Extreme selection in either direction is avoided, as a maximum yield of sugar is usually associated with a moderately high percentage of sugar, while an

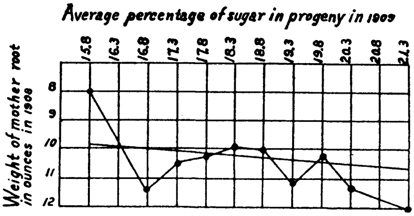

FIG. 21.—To accompany table XXIII

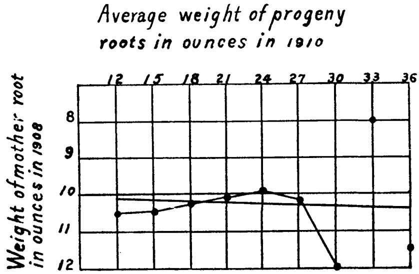

FIG. 22.—To accompany table XXIV

extremely high percentage is generally indicative of a low tonnage. As the presence of inorganic salts lowers the percentage and prevents the extraction of about an equal quantity of sugar, selection for extractable sugar is the most ideal method to employ, but it has

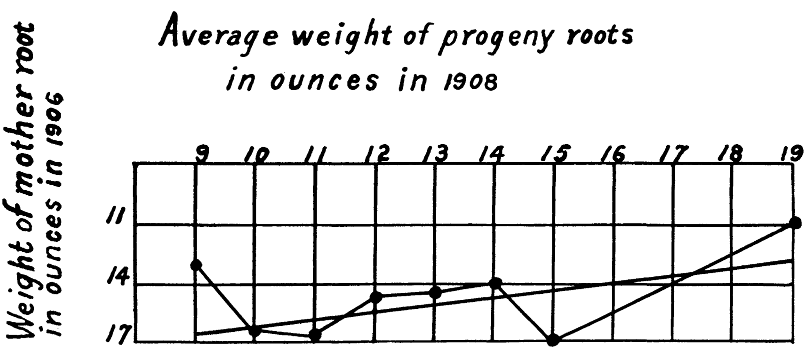

FIG. 23.—To accompany table XXV

the disadvantage that additional chemical work is required to determine the coefficients of purity. Relative merits, therefore, are more economically determined from the percentage of sugar and total yield of sugar.

VARIABILITY OF PROGENY ROWS.—Progeny rows show considerable variation even when the stand of beets is compara-

tively uniform. The coefficients of variability presented in table XXVI were determined from 173 beet families of Morrison's Kleinwanzleben grown at Madison, Wisconsin, in progeny rows of 40–50 beets each in 1912, and from 98 families of the same stock grown under similar conditions at Madison in 1913.

TABLE XXVI

VARIABILITY OF SUGAR-BEET FAMILIES

Percentage of sugar

Year	Mean	Standard deviation	Coefficient of variability
1912.....	13.60±0.068	0.998±0.048	7.34
1913.....	15.41±0.058	1.009±0.041	6.54

Yield of sugar per row

Year	Mean (gm.)	Standard deviation (gm.)	Coefficient of variability
1912.....	4276.26±32.67	637.08±23.00	14.90
1913.....	2074.70±19.64	288.18±13.88	13.89

The average variability of progeny rows expressed in percentage of the mean was 6.54–7.34 for percentage of sugar, and 13.89–14.90 for yield of sugar. Although these constants are smaller than the coefficients obtained for individual beets of the same families, 9.46–12.06 and 38.58–49.53 for percentage and yield respectively, they are fairly large for averages.

The range for percentage and yield is not shown in the table, but rows containing 80–100 per cent stand varied from 10.1 to 15.7 in percentage of sugar in 1912, and from 13.2 to 17.4 in 1913; while the extreme yields for the same periods were 2383–5654 and 1423–2746 gm. respectively. Such differences certainly offer ample opportunity for selection.

EFFECT OF SOIL IRREGULARITIES UPON THE VARIABILITY OF BEET FAMILIES.—This was determined from the records of our sugar-beet breeding experiments in which progeny rows and check rows were planted alternately.

As family differences exhibited in field tests may be due to several causes, some method had to be adopted for studying soil

effects that would eliminate such factors as family hereditary differences, and the possible use of too small a number of plants to form a representative sample of the family. This was accomplished by plotting the mean values of consecutive progeny rows

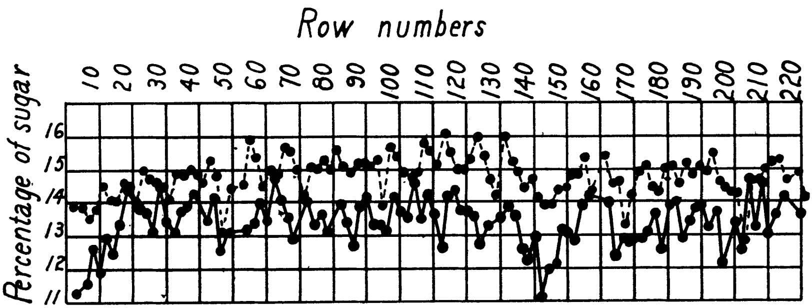

FIG. 24.—Effect of soil irregularities on percentage of sugar of check and progeny rows, strip 1, Madison, 1912; solid line indicates progeny rows; broken line, check rows.

for percentage and yield of sugar in the same order as the rows occurred in the field. Family differences in percentage or yield of sugar which show regular progression in direction are assumed

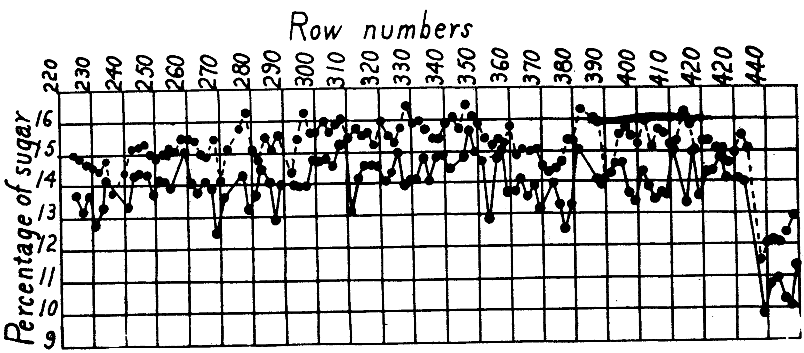

FIG. 25.—Effect of soil irregularities on percentage of sugar of check and progeny rows, strip 2, Madison, 1912; solid line indicates progeny rows; broken line, check rows.

to be due to the inequalities of the soil, while differences which show no such regularity may be due either to local soil disturbances or to other causes. A check on the results of the foregoing method is afforded by plotting the mean values of progeny rows of contigu-

ous strips whose row ends abut, and noting whether the same relative parts of the different strips show the same irregularities. Another check better adapted to show local soil irregularities and more generally applicable consists in plotting the mean values of

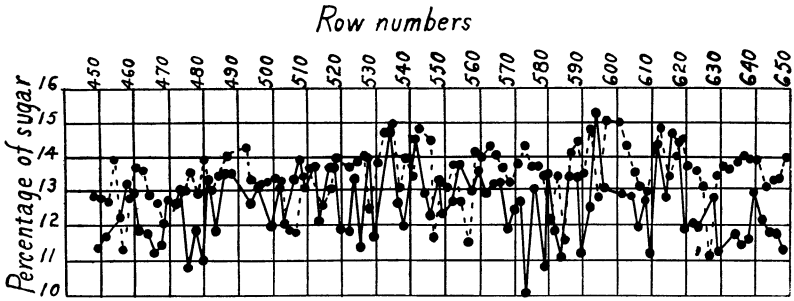

FIG. 26.—Effect of soil irregularities on percentage of sugar of check and progeny rows, strip 3, Madison, 1912; solid line indicates progeny rows; broken line, check rows.

the check rows in regular order. If these values show the same progressions as the means of the progeny rows, the effects are doubtless due to irregularities of the soil.

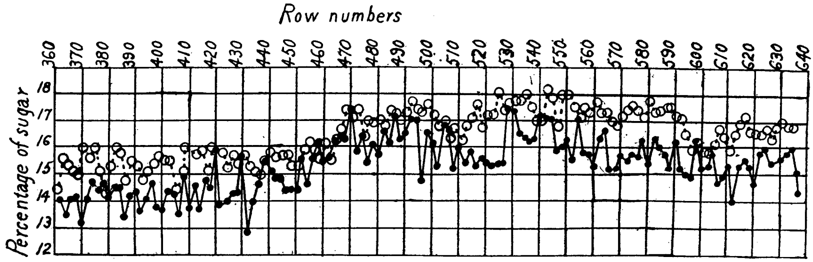

FIG. 27.—Effect of soil irregularities on percentage of sugar of check and progeny rows, Madison, 1913; solid line indicates progeny rows; broken line, check rows.

In the accompanying graphs, figs. 24–29 show the mean percentage of sugar, and fig. 30 the mean yield of sugar of consecutive progeny rows and check rows. Figs. 24–26 represent 3 contiguous strips of the same field which meet at their row ends. Strips 1 and 2 were planted on the same date, but strip 3 was plowed up and replanted on account of a poor stand. · Consequently, the beets

in strip 3 were not fully mature when harvested, as may be seen from their low percentage of sugar. The row numbers run consecutively, but only every tenth row is numbered in the figures.

The regularity in the trend of mean percentages of sugar in figs. 24–29 and of mean yields of sugar in fig. 30 shows that soil irregularities have a marked influence on the behavior of progeny rows and check rows. The close agreement of progeny rows and check rows is remarkable and shows the advantage of employing

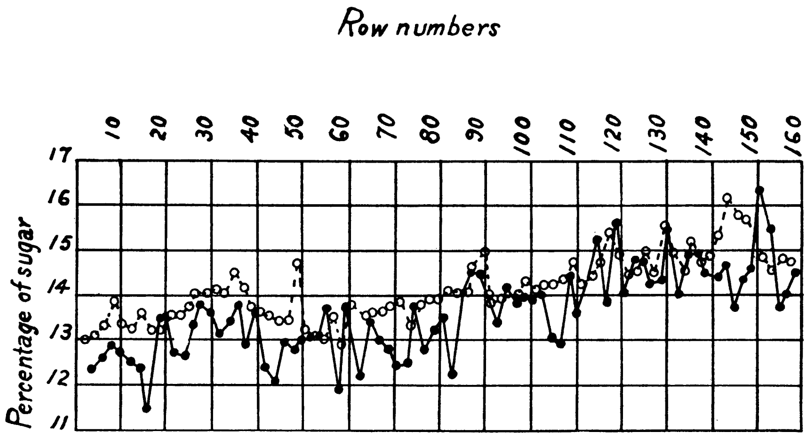

FIG. 28.—Effect of soil irregularities on percentage of sugar of check and progeny rows, Madison, 1914; solid line indicates progeny rows (Morrison's Kleinwanzleben); broken line, check rows.

frequent checks over the use of the mean value of the progeny rows as a standard of comparison. If the graphs are examined closely, it will be noted that a progeny row and its check rows frequently vary in opposite directions, although following the general trend of neighboring rows. Occasionally these peculiarities may be due to the hereditary nature of the progeny row of beets, but more frequently they are the result of local soil disturbances, as may be seen from similar deviations of check rows from their general trend. On the average the consecutive deviations of check rows from their trends appear smaller than the corresponding deviations of the progeny rows. Hence real differences between progeny rows may exist, but they are small in comparison with the fluctuations.

The only practical method of overcoming the effects of sudden soil disturbances is the employment of replications. Repeated plantings of each family between check rows of a standard variety will give a more reliable means of comparison than a single planting.

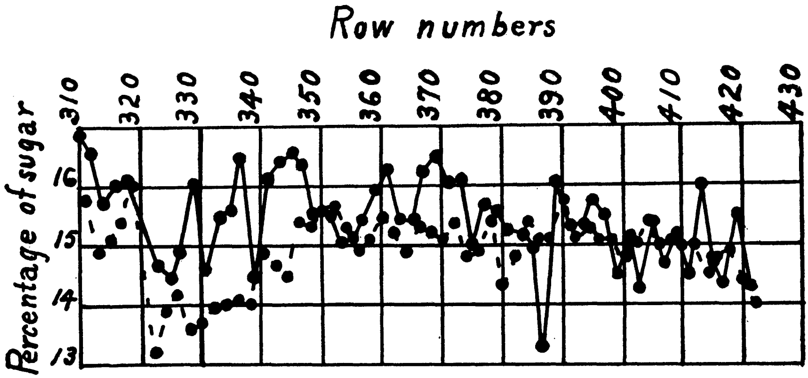

FIG. 29.—Effect of soil irregularities on percentage of sugar of check and progeny rows, Madison, 1914; solid line indicates progeny rows (Madison Original Selections); broken line, check rows.

A decided change in the direction of the graphs is shown in rows 132–155, 346–382, and 595–612 of the 3 contiguous strips in figs. 24–26. This difference is not due to the presence of a dead

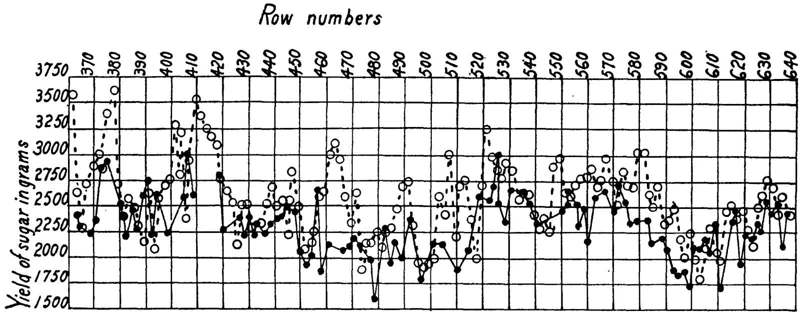

FIG. 30.—Effect of soil irregularities on yield of sugar of check and progeny rows, Madison, 1913; solid line indicates progeny rows; broken line, check rows.

furrow or back furrow, as no such areas were included in the experiment. Moreover, the disturbance covers an area 30–40 ft. wide in strips 1 and 2. The remarkable drops in percentage of

sugar in rows 435–449 has not been accounted for. These rows belong to strip 2, as indicated in the figure, and not to strip 3, as might be inferred from their behavior.

A variation of 2 per cent sugar occurs between different parts of the same field, as shown in figs. 27 and 28. These local differences are not limited to the progeny rows, but appear also in the check rows, and hence cannot be attributed to accidental groupings of good or poor families. The yields exhibited in fig. 30 are fully as variable as the percentages and show striking progressions with frequent changes in direction.

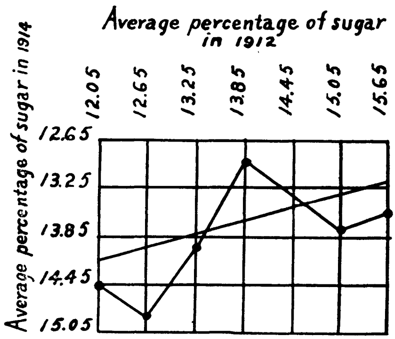

FIG. 31.—To accompany table XXVII

TRANSMISSION OF QUALITIES EXHIBITED BY SELECTED FAMILIES. —Average root weight and average percentage of sugar are the chief factors which determine the relative merits of sugar-beet

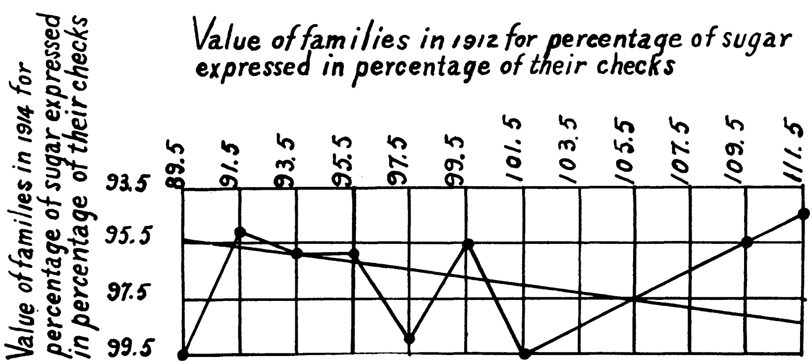

FIG. 32.—To accompany table XXVIII

families grown under uniform spacing, as they represent both yield and quality; but since these characters are very easily modified by the environment, it is doubtful whether real family differences are ordinarily distinguishable. In fact, fluctuations appearing under field conditions probably exceed the real differ-

ences between families. Tables XXVII–XXXII (summarized on p. 464) and figs. 31–36 show whether such family characters as percentage of sugar, average root weight, and average sugar content of the root are transmitted from generation to generation. Tables XXVII and XXVIII were compiled from the same data.

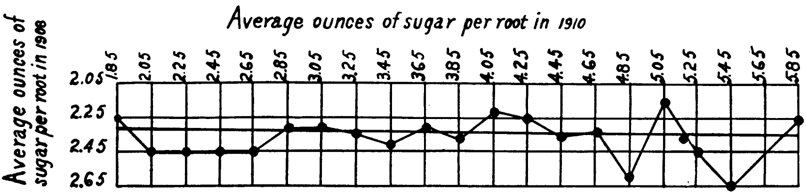

Fig. 33.—To accompany table XXIX

Table XXVII shows the relationship between the average percentages of sugar in two consecutive generations of beet families when no checks were used; table XXVIII shows the same relationship when every alternate row was employed as a check, and the value of each family was determined by dividing its percentage of sugar by the average percentage of sugar of its two contiguous checks. The families used in compiling data for tables XXIX–XXXII were planted without checks.

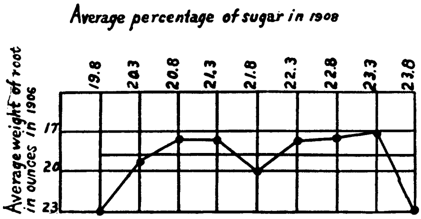

Fig. 34.—To accompany table XXX

No correlation is shown in tables XXVII and XXVIII between the percentages of sugar in two consecutive generations of a beet family. Even when every alternate row was planted as a check to offset the effects of the inequalities of the soil, the coefficient of correlation was only 0.089, while its probable error was 0.076.

Tables XXIX–XXXII furnish no evidence of correlation between average root weight or average quantity of sugar in successive generations, nor between average root weight in one generation and percentage of sugar in the following generation.

As a root's weight is negatively correlated with its percentage of sugar and positively correlated with its total sugar content, an absence of correlation between one pair of characters in tables XXVII–XXXII would signify a lack of correlation between each

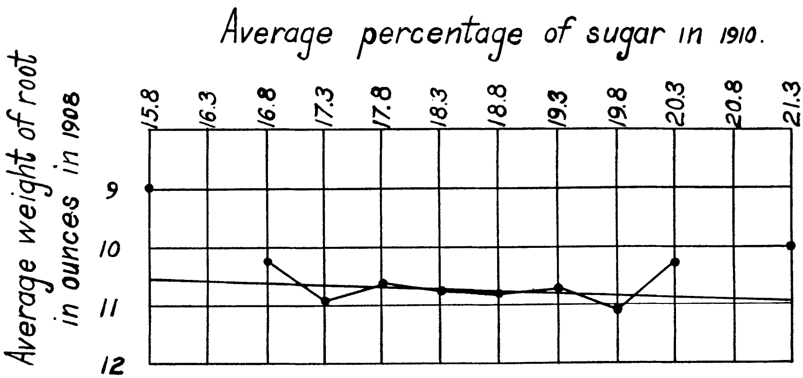

FIG. 35.—To accompany table XXXI

of the other pairs. The coefficients of correlation not only confirm this assumption but also have a corroborative effect upon one another.

Figs. 31–36 furnish a graphic illustration of the character of the material used and the reliability of the results. The trends of the empirical means of the separate classes represented by dots and connected by broken lines show a fairly close agreement with the straight line regressions. Moreover, there are no marked deviations of empirical means from the straight lines except where the classes are small. Hence the distributions are fairly regular and the biometrical constants are probably reliable.

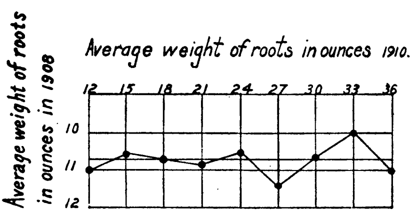

FIG. 36.—To accompany table XXXII

We are not justified in concluding from the foregoing results that no real differences in yield and quality occur, however, as real differences may be obscured by fluctuations. The most we

can say at present is that family differences of this character as determined by current field methods are not permanent.

DETERIORATION FROM LACK OF SELECTION.—There is a current belief that sugar-beets deteriorate in percentage of sugar when selection is discontinued, but this has not been proved satisfactorily. A gradual decrease for a limited period is not necessarily indicative of permanent reduction, as such environmental factors as sunshine, temperature, rainfall, time of planting, fertility of the soil, drainage, and cultural methods all vary in different years and these variations affect the percentage of sugar. In fact, the percentage may fall for 2 or 3 consecutive seasons and then rise again under more favorable conditions.

If sugar-beets deteriorate from lack of selection, commercial seed should produce poorer roots than seed of selected mothers, as it is grown from an intermediate steckling generation in which no selections are made. Such a comparison was made in 1913 by mixing seed of highly selected families of Morrison's Kleinwanzleben and planting it in alternate rows beside the commercial variety of the same stock. The results are shown in table XXXIII.

TABLE XXXIII

COMPARISON OF MORRISON'S COMMERCIAL SEED WITH SEED OF MORRISON'S SELECTED MOTHER BEETS

MORRISON'S SELECTED MOTHER-BEET SEED				MORRISON'S COMMERCIAL SEED			
Row number	Number of beets in row	Weight of row of beets in pounds	Percentage of sugar in beets	Row number	Number of beets in row	Weight of row of beets in pounds	Percentage of sugar in beets
2........	68	46.5	15.0	3.....	67	43.5	15.9
4........	68	37.0	15.0	5.....	65	32.5	15.2
6........	60	39.5	15.2	7.....	62	37.0	15.4
8........	72	40.0	15.1	9.....	70	39.5	15.5
10........	62	38.0	15.2	11.....	72	43.0	15.3
12........	82	47.0	14.9	13.....	69	36.5	15.7
14........	85	49.5	15.0	15.....	57	33.0	15.7
16........	74	45.0	14.9	0.....	0	0	0
Averages	71.4	42.8	15.0	....	66	38.0	15.5

Average weight of root in grams: Morrison's commercial, 259.91; Morrison's selected, 271.70.

In every instance the commercial seed produced the richer roots. They were somewhat smaller than the roots from seed of selected mothers, averaging 11.79 gm. less per plant, but this is

equivalent to only about 0.03 per cent sugar, while the average difference obtained was 0.5. Hence the commercial seed not only failed to show deterioration, but actually appeared to improve. Similar results were observed between the variety and its more

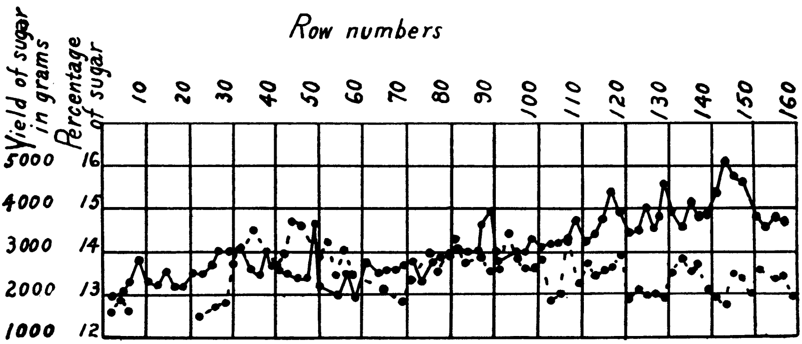

FIG. 37.—Effect of soil irregularities on relationship between percentage of sugar and yield of sugar in consecutive check rows, Madison, 1914; solid line indicates percentage of sugar; broken line, yield of sugar.

highly selected families in 1912 which led to the planning of this experiment.

RELATIONSHIPS BETWEEN PERCENTAGE OF SUGAR, YIELD OF SUGAR, AND AVERAGE ROOT WEIGHT OF SUGAR-BEET ROWS.—As

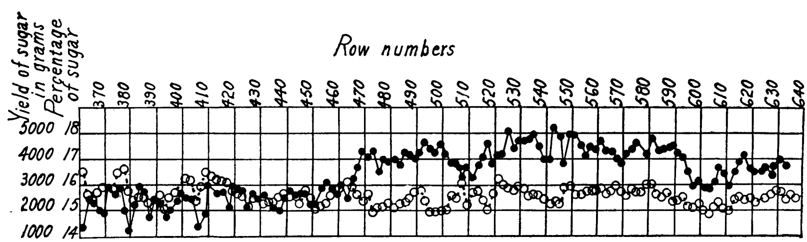

FIG. 38.—Effect of soil irregularities on relationship between percentage of sugar and yield of sugar in consecutive check rows, Madison, 1913; solid line indicates percentage of sugar; broken line, yield of sugar (corrected yield).

beets are grown under approximately uniform spacing, the same correlations which obtain between weight, percentage of sugar, and yield of sugar in individual roots would be expected to occur in sugar-beet rows. An ideal stand is never obtained under field

conditions, however, and as this may cause a deviation from the theoretical relationships, the actual relationships have been determined by plotting in figs. 37–50 the mean values of consecutive rows containing 80–100 per cent stand.

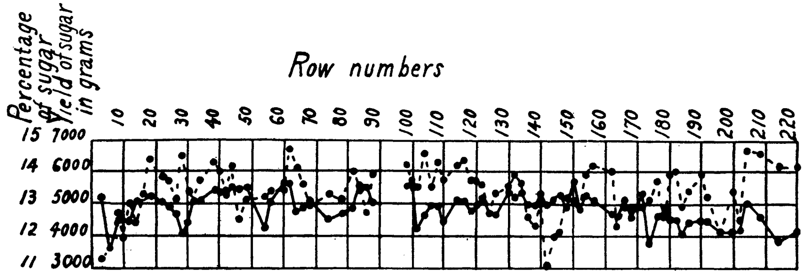

FIG. 39.—Effect of soil irregularities on relationship between percentage of sugar and yield of sugar in progeny rows, Madison, 1912; solid line indicates yield of sugar (corrected yield); broken line, percentage of sugar.

Figs. 37–41 show no correlation between percentage of sugar and yield of sugar in beet rows. In some places the graphs seem to follow a similar trend, as in rows 390–460 and 600–630 of fig. 38,

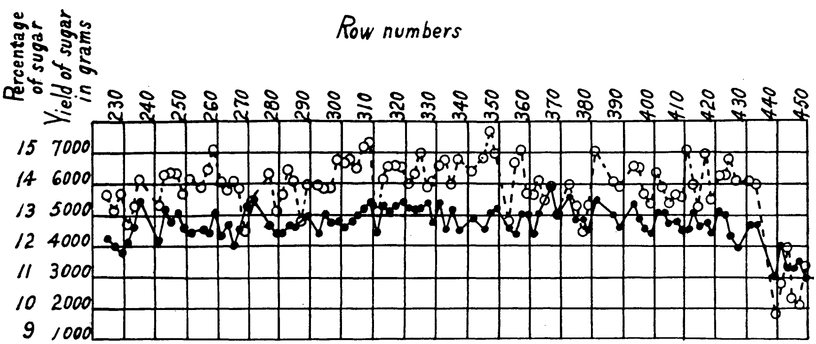

FIG. 40.—Effect of soil irregularities on relationship between percentage of sugar and yield of sugar in progeny rows, Madison, 1912; solid line indicates yield of sugar (corrected yield); broken line, percentage of sugar.

and 370–440 of fig. 40; but in other places, as in rows 100–160 of fig. 37 and 450–520 of fig. 41, they apparently diverge. On the average, therefore, percentage and yield vary independently.

A negative correlation occurs between percentage of sugar and average weight of root per row. The most marked occurrence of this kind is shown in the trends of figs. 44 and 45. Divergence is fully as evident, however, in more localized areas and even in

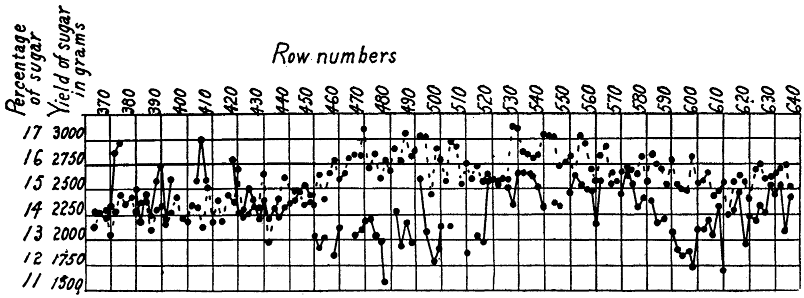

FIG. 41.—Effect of soil irregularities on relationship between percentage of sugar and yield of sugar in consecutive progeny rows, Madison, 1913; solid line indicates yield of sugar (corrected yield); broken line, percentage of sugar.

individual rows. Compare in this regard the divergence of graphs in rows 47, 72, 127, 157, and 162 of fig. 42, and 240–250, 255–265, and 370–380 of fig. 43.

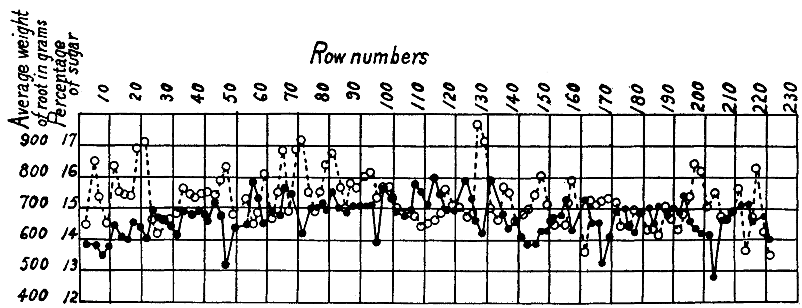

FIG. 42.—Effect of soil irregularities on relationship between percentage of sugar and average weight of root in consecutive check rows, Madison, 1912; solid line indicates percentage of sugar; broken line, average weight of root per row.

A high positive correlation is shown between average weight of root and yield of sugar per row in figs. 46–49. Whenever either graph progresses in a given direction, it is closely followed by the other member of the pair. This is most conspicuous in figs. 47 and 48.

As corrected yields, that is, yields corrected for a full stand by means of the regression coefficient between number of roots and yield of sugar per row, were employed in figs. 38–41, and actual yields in figs. 37 and 46–49, their relationship has been determined

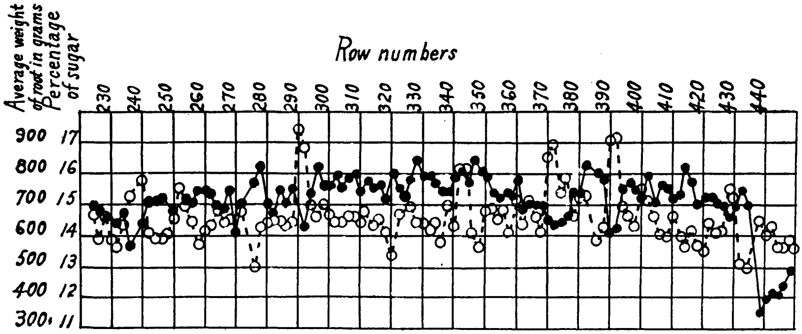

FIG. 43.—Effect of soil irregularities on relationship between percentage of sugar and average weight of root in consecutive check rows, Madison, 1912; solid line indicates percentage of sugar; broken line, average weight of root per row.

and illustrated in fig. 50. Only rows containing a stand of 80–100 per cent are connected. The *o*'s of the unconnected rows represent actual yields, and the *x*'s represent corrected yields of rows containing less than 80 per cent stand.

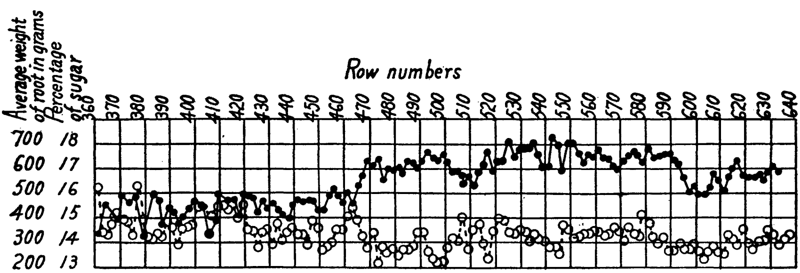

FIG. 44.—Effect of soil irregularities on relationship between percentage of sugar and average weight of root in consecutive check rows, Madison, 1913; solid line indicates percentage of sugar; broken line, average weight of root per row.

The graphs show practically the same progressions and trends. The use of actual yields instead of corrected yields, therefore, in some of the figures did not materially alter the results of comparison.

The relationships exhibited in the foregoing figures between yield and quality of beet rows have a very important bearing upon sugar-beet improvement. Selection for yield of sugar regardless

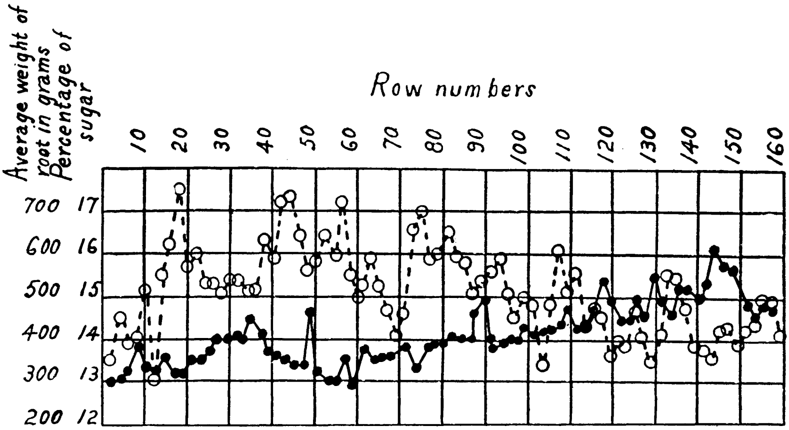

FIG. 45.—Effect of soil irregularities on relationship between percentage of sugar and average weight of root in consecutive check rows, Madison, 1914; solid line indicates percentage of sugar; broken line, average weight of root per row.

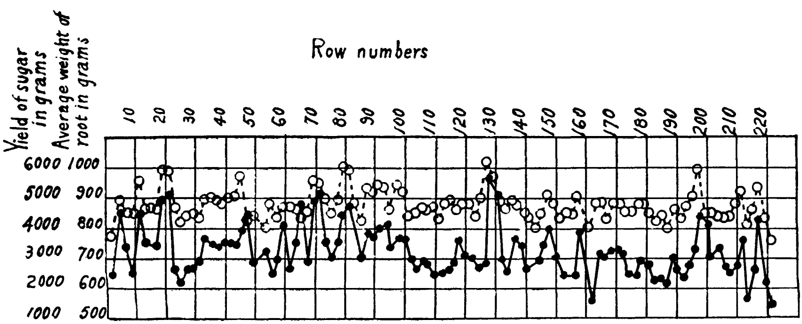

FIG. 46.—Effect of soil irregularities on relationship between average root weight and yield of sugar in consecutive check rows, Madison, 1912; solid line indicates average weight of root per row; broken line, yield of sugar.

of percentage would increase the size of the root but decrease the proportion of extractable sugar, as large roots have, not only a lower percentage of sugar than small roots, but also a lower coefficient of purity. On the other hand, selection for percentage alone would decrease the tonnage, as percentage of sugar is

negatively correlated with average weight of root. Both yield and percentage, therefore, should be considered in making selections. Obviously, the best single character is yield of extractable

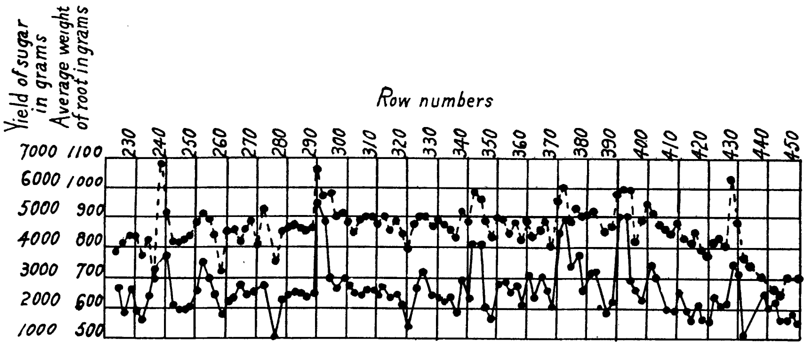

FIG. 47.—Effect of soil irregularities on relationship between average root weight and yield of sugar in consecutive check rows, Madison, 1912; solid line indicates average weight of root per row; broken line, yield of sugar.

sugar, but even with its use a lower limit should be set for percentage. The extra cost of determining coefficients of purity used in calculating extractable sugar, however, would probably condemn the use of this method for commercial purposes.

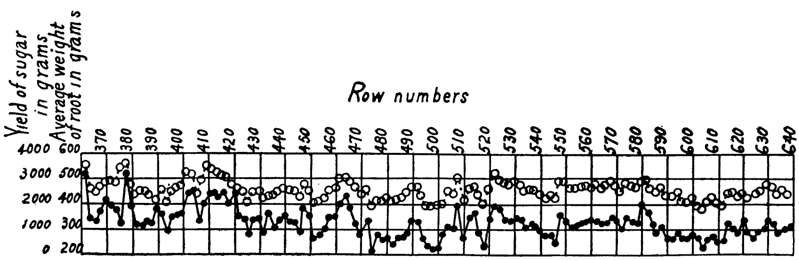

FIG. 48.—Effect of soil irregularities on relationship between average root weight and yield of sugar in consecutive check rows, Madison, 1913; solid line indicates average weight of root per row; broken line, yield of sugar.

Discussion of results

The results of the foregoing experiments may appear, at first sight, to disprove the possibilities of beet improvement, but this is only apparent. The fact of past improvement is beyond

question, as the average percentage of sugar, average size of root, and yield of sugar per acre have been increased greatly. Moreover, there is no valid reason for assuming that these characters have reached their maximum development. The differences exhibited by the varieties Morrison's Kleinwanzleben, Kleinwanzleben's Original, and Madison Original Selections, as illustrated in fig. 1, show that sugar-beet varieties may still be altered by breeding. For the sake of discussion it will be assumed that beets are improved

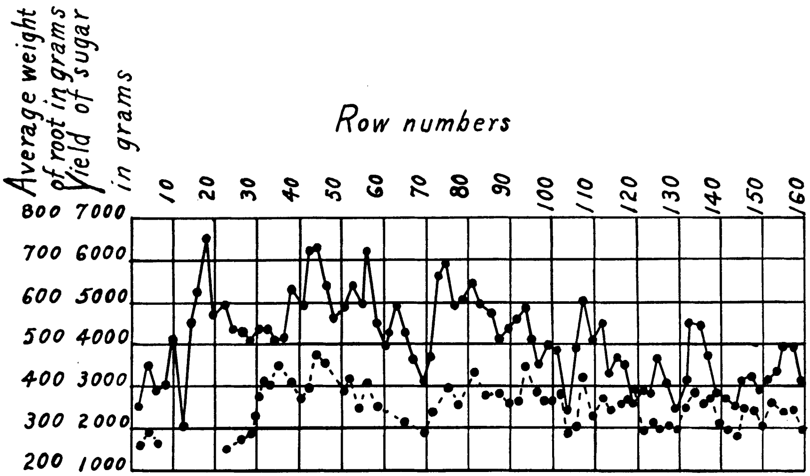

FIG. 49.—Effect of soil irregularities on relationship between average root weight and yield of sugar in consecutive check rows, Madison, 1914; solid line indicates average weight of root per row; broken line, yield of sugar.

either (1) by a gradual accumulation of small variations through the process of continuous selection, or (2) by the isolation and multiplication of an occasional mutation.

Continuous selection is based upon the theory that "like begets like," or the tendency of superior individuals to transmit their qualities to their progeny. As shown in the foregoing tables and graphs, the best roots transmit no better qualities than do mediocre roots. Their differences are mere fluctuations, therefore, and have no influence on beet improvement. This has no bearing, however, upon the value of continuous selection when applied to real differences, as the possibilities of improvement through a

gradual accumulation of small real differences is still an open question. Since aside from the progeny test no method of distinguishing real differences between beet roots has been in vogue, the selection of choice roots by chemical and physical means probably has played no part in sugar-beet improvement except where an occasional root has mutated and thus given rise to a superior physiological species.

The real differences between sugar-beet families are usually very small, as may be noted from the difference in size of corresponding

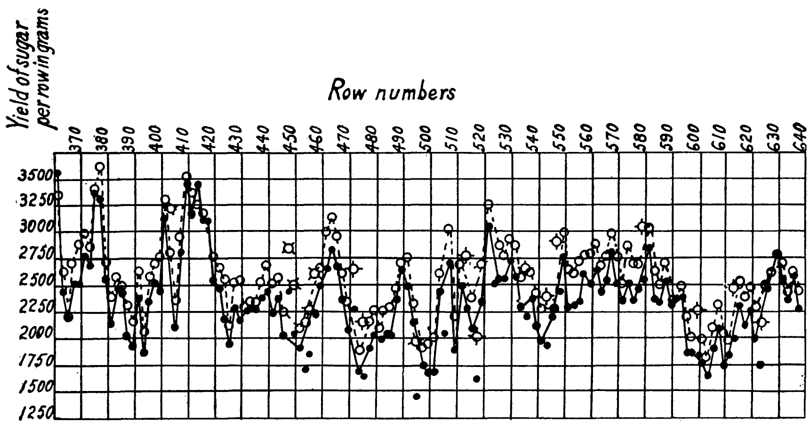

FIG. 50.—Relationship between actual yield and corrected yield of sugar in consecutive check rows, Madison, 1913; solid line indicates actual yield; broken line, corrected yield.

variations of individual check and progeny rows. In fact, their real differences are greatly exceeded by their fluctuations.

Both the best and the poorest families transmit average qualities. Hence continuous selection does not seem to be an efficient means of improvement. Moreover, it is difficult to conceive how it could have played any important part in sugar-beet improvement in the past.

The isolation of mutations probably offers more promising opportunities for improving beets than continuous selection. Our records show no evidence of mutations, but the numbers are too small to disprove their occasional occurrence. Moreover, no table presented contains data for more than two consecutive generations,

which is insufficient to determine with certainty either the fact or the frequency of their occurrence.

The mutations sought by the sugar-beet breeder are not necessarily morphologically distinguishable from other individuals of the variety. They are plants which have undergone constitutional alteration and hence possess new potential limits of physiological elasticity which they transmit to their progeny.

The valuable plants of this class are those which transmit a higher sugar-producing capacity to their progeny than possessed by the variety regardless of their own qualities. In fact, we are hardly justified in assuming that the mutants themselves possess conspicuously high qualities. They are more likely to lie near the mean of the variety than at either limit of its range. This is illustrated for a particular case in fig. 51.

The frequency polygon A shows the actual distribution of 3784 beets for percentage of sugar, while A^1 shows a similar distribution of the hypothetical progeny of a supposed mutant. Their means, represented by the vertical lines M and M^1, are 17.67 and 18.67 respectively, and hence differ by 1 per cent sugar. The bulk of the mutant's progeny in polygon A^1 lie between classes 17–21, which is about 22 times as great as the proportion lying above 21. Since the records of the progeny are an expression of the potentialities of the mutant, the mutant itself is 22 times as likely to lie between 17–21 in the original population of polygon A as above this group.

The possibilities of finding a mutant by taking a limited number of roots from the material represented in polygon A are somewhat greater in the classes above 21 than between 17–21. There are in polygon A about 100 times as many individuals in the classes 17–21 as above 21. If the mutant were equally likely to appear in either group, the chances of finding it by taking an equal number of roots from each group would be 0.01 as great in classes 17–21 as in the population above 21. However, we found that the chances of the mutant's lying in group 17–21 are 22 times as great as in the other group, therefore the possibilities of finding it by drawing an equal number of roots from each group are not as 0.01:1, but as 0.22:1, or about 1:4.5. If the whole polygon A were divided into two groups, so that all the roots containing 21 per cent sugar

or less were to lie in one group and all the remaining roots in the other, the chances of finding the mutant by taking an equal number of roots from the respective groups would be as 1:6.

The ratios 1:4.5 and 1:6 are small and hardly warrant the expenditure of large sums of money for chemically selecting

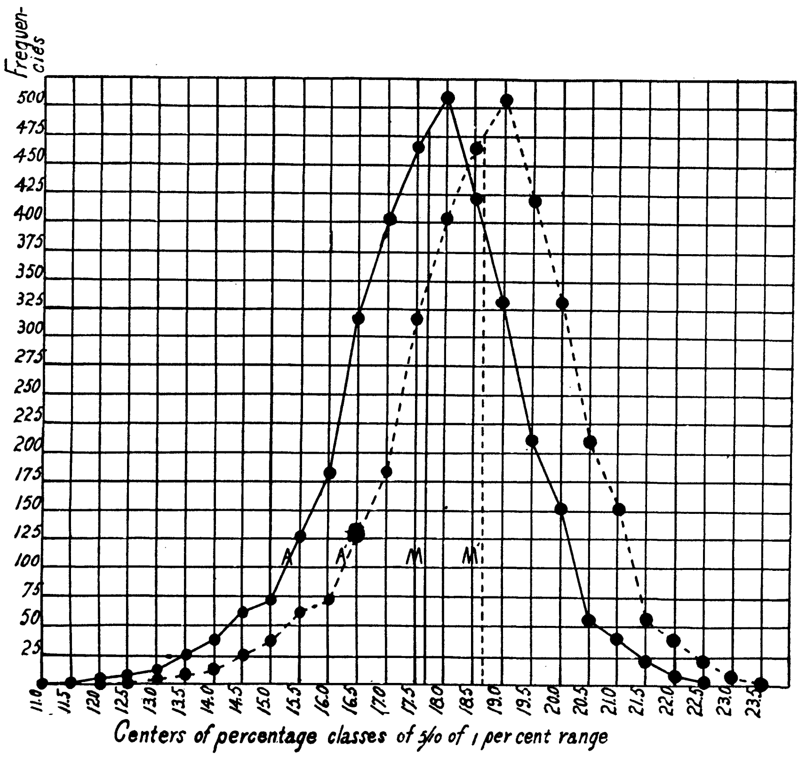

FIG. 51.—Most probable location of mutants

individual roots of high sugar content to increase the probability of finding mutants. Tests of 6–10 times the usual number of roots taken at random would be more economical and fully as effective.

As continuous selection has resulted in failure and only the mutation theory remains as a promising means of sugar-beet improvement, some very decided changes should be made in methods. First of all, more efficient methods of making tests should be devised in order to reduce the effects of soil irregularities

and distinguish real differences. This can best be accomplished by a more frequent use of checks and replications. Replications, however, require a liberal seed supply. Although a single plant ordinarily produces a limited quantity of seed, there are means of increasing the normal yield considerably. A root divided into halves and planted at the customary distances will produce nearly twice as much seed as a whole root. Moreover, seed yield is greatly influenced by soil fertility. A rich soil stimulates under a proper temperature the production of flowering shoots and enables the plant to mature a large crop. If these means are employed to increase the average seed production and only the heaviest seed-yielding plants are used for the preliminary tests, a sufficient quantity of seed may be obtained to make a large number of plantings from each individual. When a sufficient number of replications are made to distinguish real differences, only the few best families should be saved. As roots of a single family are apparently of equal breeding value, it is advisable to plant all the roots of each family in an isolated group, where distance or intervening obstructions will prevent their crossing with plants of a different family. There is apparently no gain from harvesting the plants of each family separately. Moreover, the combined yields of the individual plants of a family are necessary to make a satisfactory test of the relative merits of the families the following year. Thereafter, no further selection would appear to be necessary. If all but 3 or 4 of the best families are discarded and the remainder mixed and prevented from crossing with poorer stock, they probably will maintain their vigor and are not likely to deteriorate in the absence of further selection.

The possibility of further improvement apparently lies in the isolation of more valuable mutants, but whether the original stock or the new variety should be used as a source of material can be determined only when it is known in which the mutants will occur with the greater frequency.

SUMMARY OF BIOMETRICAL CONSTANTS COMPILED FROM TABLES II–XI, XIV–XXV, AND XXVII–XXXII

No. of table	Characters	Mean	Standard deviation	Coefficient of correlation
II	Percentage of sugar in root in 1905.....	19.23±0.042	0.977±0.029	
	Yield of seed per beet in ounces in 1906.	8.94±0.179	4.199±0.126	−0.027 ±0.039
III	Percentage of sugar in root in 1906.....	20.77±0.065	1.296±0.046	
	Yield of seed per beet in ounces in 1907.	11.87±0.267	5.357±0.189	0.074 ±0.050
IV	Percentage of sugar in root in 1908.....	23.60±0.056	1.021±0.039	
	Yield of seed per beet in ounces in 1909.	9.68±0.305	5.547±0.216	−0.157 ±0.054
V	Percentage of sugar in root in 1909.....	20.18±0.052	1.63 ±0.036	
	Yield of seed per beet in ounces in 1910.	3.94±0.139	4.36 ±0.099	0.098 ±0.032
VI	Percentage of sugar in root in 1910.....	18.72±0.031	1.16 ±0.022	
	Yield of seed per beet in grams in 1911..	215.90±3.115	117.29 ±2.202	0.049 ±0.026
VII	Quantity of sugar per root in ounces in 1905..............................	2.64±0.037	0.87 ±0.026	
	Yield of seed per beet in ounces in 1906.	8.86±0.176	4.14 ±0.124	−0.082 ±0.026
VIII	Quantity of sugar per root in ounces in 1906..............................	3.89±0.086	1.725±0.060	
	Yield of seed per beet in ounces in 1907.	11.78±0.268	5.407±0.190	0.081 ±0.049
IX	Weight of root in ounces in 1905.......	13.94±0.202	4.748±0.143	
	Yield of seed per beet in ounces in 1906.	8.94±0.179	4.200±0.126	−0.056 ±0.042
X	Weight of root in ounces in 1906.......	19.42±0.470	9.480±0.330	
	Yield of seed per beet in ounces in 1907.	11.82±0.265	5.341±0.186	0.024 ±0.050
XI	Weight of root in ounces in 1910.......	18.96±0.151	5.78 ±0.106	
	Yield of seed per root in grams in 1911..	216.75±3.086	118.44 ±2.182	0.071 ±0.026
XIV	Percentage of sugar in mother roots in 1908..............................	20.53±0.032	0.472±0.023	
	Average percentage of sugar in progeny in 1910.........................	13.60±0.068	0.998±0.048	−0.149 ±0.067
XV	Percentage of sugar in mother roots in 1912..............................	16.31±0.081	1.065±0.058	
	Value of progeny rows for percentage of sugar in 1914 expressed in percentage of their checks....................	96.46±0.114	4.499±0.243	−0.040 ±0.076
XVI	Percentage of sugar in mother roots in 1912..............................	16.31±0.081	1.065±0.058	
	Average percentage of sugar in progeny in 1914.........................	13.61±0.074	0.972±0.052	−0.090 ±0.076
XVII	Ounces of sugar in mother root in 1908..	2.44±0.029	0.53 ±0.021	
	Ounces of sugar per beet in progeny in 1910............................	3.70±0.038	0.68 ±0.027	0.032 ±0.050
XVIII	Ounces of sugar in mother root in 1906..	3.28±0.107	1.21 ±0.076	
	Ounces of sugar per beet in progeny in 1908............................	2.43±0.032	0.36 ±0.023	−0.100 ±0.088
XIX	Ounces of sugar in mother root in 1907..	4.67±0.063	1.413±0.044	
	Ounces of sugar per beet in progeny in 1909............................	4.01±0.040	0.897±0.028	0.104 ±0.044
XX	Weight of mother root in ounces in 1908	10.31±0.121	2.19 ±0.086	
	Ounces of sugar per root in progeny in 1910............................	3.74±0.041	0.75 ±0.029	0.092 ±0.055
XXI	Weight of mother root in ounces in 1906	16.22±0.548	6.19 ±0.388	
	Ounces of sugar per root in progeny in 1908............................	2.41±0.032	0.36 ±0.023	−0.115 ±0.087
XXII	Weight of mother root in ounces in 1906	16.22±0.548	6.19 ±0.387	
	Average percentage of sugar in progeny in 1908.........................	21.73±0.074	0.84 ±0.053	0.168 ±0.086

SUMMARY OF BIOMETRICAL CONSTANTS COMPILED FROM TABLES II–XI, XIV–XXV, AND XXVII–XXXII—*Continued*

No. of table	Characters	Mean	Standard deviation	Coefficient of correlation
XXIII	Weight of mother root in ounces in 1908	10.29±0.121	2.19 ±0.086	
	Average percentage of sugar in progeny in 1910	18.50±0.047	0.84 ±0.033	0.055 ±0.054
XXIV	Weight of mother root in ounces in 1908	10.25±0.120	2.15 ±0.085	
	Average weight of progeny roots in ounces in 1910	20.61±0.242	4.33 ±0.171	0.023 ±0.056
XXV	Weight of mother root in ounces in 1906	15.74±0.565	6.33 ±0.400	
	Average weight of progeny roots in ounces in 1908	11.28±0.142	1.59 ±0.100	−0.095 ±0.089
XXVII	Average percentage of sugar in beet families in 1912	14.07±0.063	0.826±0.045	
	Average percentage of sugar in beet families in 1914	13.61±0.074	0.972±0.052	−0.229 ±0.072
XXVIII	Value of beet families for percentage of sugar in 1912 expressed in percentage of their checks	96.01±0.329	4.313±0.233	
	Value of beet families for percentage of sugar in 1914 expressed in percentage of their checks	96.35±0.330	4.315±0.233	0.089 ±0.076
XXIX	Ounces of sugar per root in beet families in 1908	2.33±0.014	0.24 ±0.010	
	Ounces of sugar per root in beet families in 1910	3.69±0.042	0.70 ±0.030	0.031 ±0.060
XXX	Average weight of root in ounces in beet families in 1906	18.8 ±0.391	4.30 ±0.277	
	Average percentage of sugar in beet families in 1908	21.7 ±0.077	0.85 ±0.055	0.056 ±0.091
XXXI	Average weight of root in ounces in beet families in 1908	10.75±0.070	1.15 ±0.049	
	Average percentage of sugar in beet families in 1910	18.52±0.054	0.89 ±0.038	0.054 ±0.060
XXXII	Average weight of root in ounces in beet families in 1908	10.74±0.067	1.139±0.047	
	Average weight of root in ounces in beet families in 1910	20.57±0.261	4.45 ±0.185	−0.0003±0.059

Summary

1. Differences in the size and sugar content of individual beet roots show no evidence of inheritance. They are fluctuations, therefore, and apparently play no part in beet improvement.

2. No correlation was discoverable between percentage or quantity of sugar in sugar-beet roots of ordinary sizes and their yield of seed, nor between their yield of seed and the average percentage of sugar in their progeny.

3. The fluctuations of beet families planted in progeny rows in alternation with check rows exceeded their real differences, but real differences were distinguishable by the use of a large number of replications (cf. fig. 1).

4. Areas of beets in an apparently uniform field of small dimensions showed a difference of 2 per cent sugar.

5. Percentage of sugar and yield of sugar of sugar-beet rows vary independently. Progeny rows should be graded on both percentage and yield of sugar, therefore, or on yield of extractable sugar.

6. The average weight of root per row increases with yield of sugar and decreases with percentage of sugar.

7. The discontinuance of selection for one generation caused no deterioration in percentage of sugar. In fact, there was some apparent gain.

8. No improvement in yield or percentage of sugar was obtained by continuous selection. Both the good and the poor families transmitted average qualities.

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